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Web Based Chiller Plant Optimal Control-A Case Study

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Abstract

Chiller plants are often operated in drastically different conditions other than the design. Consequently, the optimal control has to be developed and implemented based on the real operation conditions to improve the efficiency. This study presents a Web-based online control system implementation in a chiller plant for a hospital as a case study. The primary optimization measures include an optimal number of chillers in operation, optimal chilled water and condensing water pump speeds, and optimal cooling tower fan speed. The measured chiller plant savings is 24.6%.

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Keywords: Chiller Plant; Optimal control; Energy Savings verification; Energy efficiency; Networked formation

1. Introduction

In the past few decades, the design of chiller plant mainly relied on the design load which is normally higher than the practical load in order to satisfy the indoor comfort requirements of the Building. This tradition running mode may lead to an excessive energy usage in public buildings now a day. Energy savings retrofit in exciting buildings provides an opportunity for overall reduction in the primary energy [1]. Control management is growing as an essential strategy of energy savings along with the intersection between the automation field and the HVAC field. The energy consumption of chiller plants may account for 40% to 50% of the total energy consumption for the buildings in China [2]. Various studies proposed multiple methods to control the chiller plant.

Chan, Cary W H described a save mode chiller control logic to save energy consumption by operating the chillers at near full conditions due to the mismatch of cooling load demand and chilled water flow demand in decoupled

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bypass systems [3]. Hydeman et al. provided a parametric model to sort out the combination control sequences based on simulation tools along with operating characteristics of the chiller plants [4]. B.C. Ahn et al. developed the optimal control using a quadratic representation to obtain the optimal set temperatures. Moreover, the optimal control can minimize globe energy consumption without reducing the indoor comfort. The overall electromechanical equipment models came from the TRNSYS, a simulation program [5]. Xiupeng Wei et al. presented a data-driven approach to the nonlinear and non-convex problem for the chiller plant and tested in a simulation [6].

Some studies are based on simulation models which were mainly dealt with the ideal conditions. The variable flow of chilled water and condenser water is increasingly employed to reduce pumping energy in chilled water systems. Controlling the flow of water loop including chilled water loop and condensing water loop to reduce the water pump energy consumption is another perspective among the researchers. Lucas B.et al. presented the chiller plant operation may retain fully loaded regardless of the chilled water temperatures and header differential pressures through controlling the chilled water pumps [7]. Zhenjun Ma.et al. presents an online control model by using a genetic algorithm as a tool for the building cooling water system. The performance map and exhaustive search were utilized to find an optimal measure. Their study was about online control under the limit of operating conditions and load requirement [8]. Besides the advantage of energy savings, F.W.Yu et al. demonstrated the economic benefits of optimal control for cooling towers and condensing water pumps via evaluating the operating cost savings in a hotel building. The analysis report was also to help the managers to recognize the cost-effective measure for a practical building [9].

This study presents a web-based online control formation which can be directly used in practical chiller plant. According to the models suggested in the previous studies, adaptive measures were implemented in the control system. By using the control formation and control measures, the energy savings and energy efficiency improvement can be quantitatively validated in a real chiller plant.

2. Control system formation and logic

The chiller plant concerned in this research services a comprehensive municipal hospital building in southern China. This building has a gross floor area of about 497,000m^2. There are three chillers in the plant which were configured by three loops of distribution pipeline network for liquid transportation. The heat is exhausted by means of three mechanical draft cooling towers. Through the investigation, there was a simple control system just for the function of a turn on and turn off in the chiller plant. The simple control system could not satisfy the function requirement for the supervision and control. The operating decision of the chiller plant relied on the subjective verdict from the manager in the field. This mode did not have benefit to the safe operation and energy savings purpose. Usually the chiller worked under partly load condition and the energy consumption was high. The differential of temperature at evaporator is much less than the set value. All of the transport devices did not have frequency units that will lead to high motor power. The historical data was recorded manually by the manager hour by hour. To sum up, the chiller plant previously had the characteristic of higher energy consumption and worse stability.

2.1. Control system design

Each electric equipment operates independently and has complex relevant with each other in a chiller plant. These characteristics require not only separated control scheme but also a global control scheme from the perspective of the entire chiller plant. Distributed control system was adopted on account of the advantages of centralized management and decentralized control. It is suitable for the energy savings retrofit in a large chiller plant. All of the field devices was supervised and controlled by the distributed control system in this practical chiller plant. Considering the complicated relationship in the chiller plant, the distributive formation was designed and as shown in Fig. 1. In order to achieve a higher transmission rate of information, the Modbus communication protocol was used as a connection in the formation.

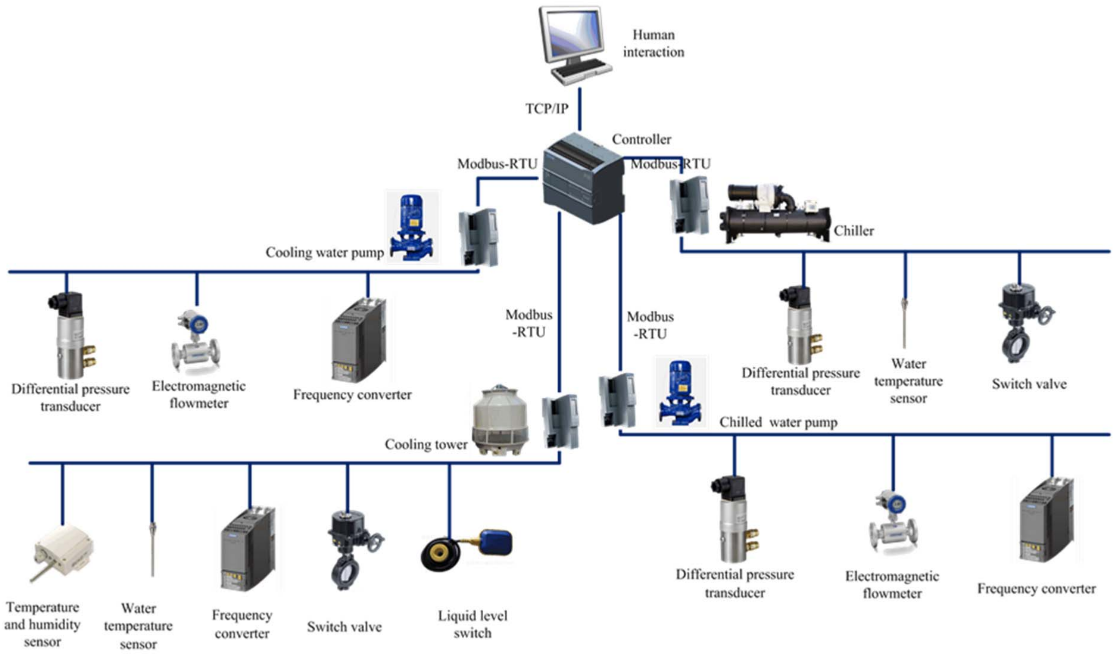

Fig. 1. The web-based distributive formation of the field devices.

2.2. Optimal control of chillers

The optimal control for multi-chillers has two aspects, the number of operating chillers control and the temperatures set point control. The differential temperature of chilled water and the set point temperature of chilled water were used to alter the number of operating chillers. The supply temperature of chilled water and the return temperature of condensing water were reset separately according to the return temperature from the terminal and the temperature outside. The indoor comfort can be sustained by means of chillers control measures.

2.3. Optimal control of chilled water pump

The water pump is a part of the primary transmission equipment in a chiller plant. The main methods to control the water pumps are variable frequency control, valve regulation and the amount control and the methods can be easily applied in existing constructions. Previous studies had validated that variable frequency control and the amount control for chilled water pump can reduce the energy consumption and simultaneously maintain the thermal comfort in the rooms under the condition of the uncontrollable terminal. Using temperature to control the frequency is more suitable for the buildings with uncontrollable terminal than other frequency control. Therefore, the chilled water pump was controlled by PID (Proportion Integration Differentiation) strategy according to the deviation between the actual differential temperature and the differential temperature set point. In terms of the efficiency of the pump, the number of pumps can be controlled.

2.4. Optimal control of condensing water pump

The frequency control of condensing water pump can ensure the pumps operated by the optimal point which could meet the cooling requirement. This optimal control can greatly decrease the energy consumption in condensing water loop in a partly load chiller plant. Under the initial conditions, this paper adopted the differential temperature stratagem to control the frequency of condensing water pumps. Similarly, with the chilled water pumps, the frequency is controlled by the temperature deviation and the number is controlled by the efficiency of the pump.

2.5. Optimal control of cooling tower fan

The cooling tower fan is the lowest energy consumption equipment in the chiller plant. The operating status of the fan decides the return temperature of condensing water, despite the consumption of cooling tower fan is lesser, so that the fan may have strongly effect on the energy consumption and COP (coefficient of performance) of the chiller plant. The frequency of the fan was controlled by the deviation between the condensing water inlet temperature T_{icw} and the condensing water inlet temperature set point T_{cwiset}. In addition, the cooling tower fan will be turned off if the condensing water inlet temperature is lower than the limit. The global logic framework for the practical chiller plant can be shown in Fig. 2. Where ΔT is the differential between inlet and outlet temperature, F is the operating frequency of electric equipment, F_{low} means the lowest limit of the frequency, subscript set means the value is the set point value and subscripts *cw*, *ct* and *ch* are respectively for cooling water pump, cooling tower fan and chilled water pump.

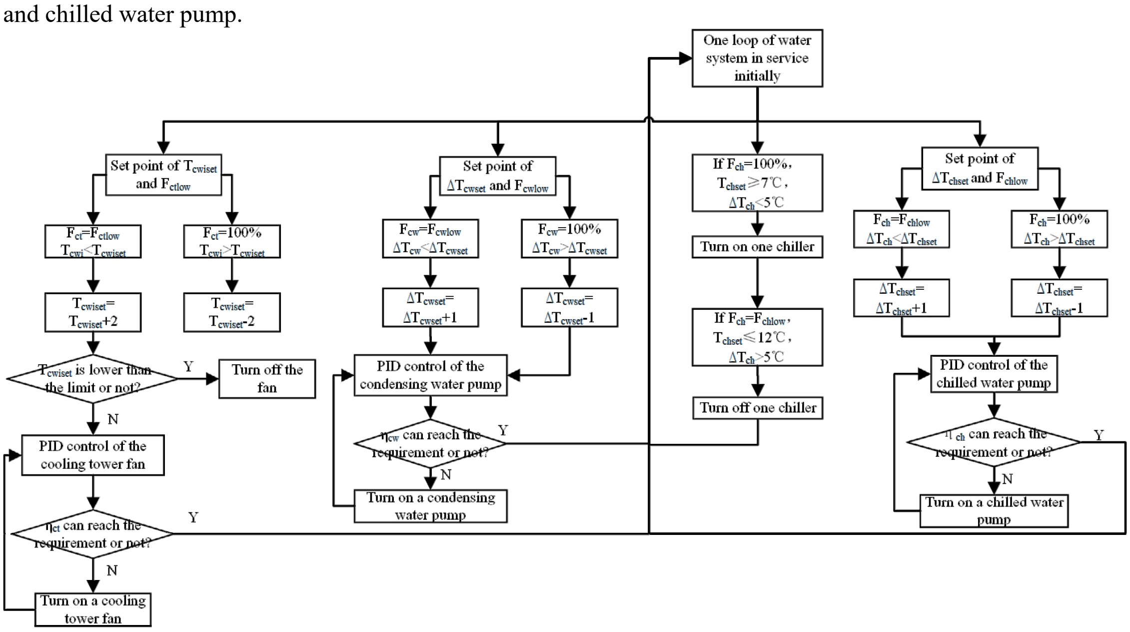

Fig. 2. The global logic framework of the practical chiller plant.

3. Results

To analyze the control effect of the chiller plant, a couple of typical day from operating record before and after energy savings retrofit which has similar curves for the outdoor temperature and humidity as well as the indoor load were chosen to be compared. According to the previous operating record, the detail of operating status of each electric equipment is provided in Table 1. After the implementation of the web-based control system, the operating status of each electric equipment is illustrated in Fig. 3.

Table 1 presents the operating status of each equipment before energy savings retrofit according to the previous operating record. There were two chillers operated all day long and the number of running devices only depended on the subjective consciousness of managers. Except for the chillers, all of the pumps and fans operated with fixed frequency.

Table 1. The operating status of electric equipment before the energy savings retrofit.

Electric equipment	Operating status		
	1#	2#	3#
Chiller	Off	On	On
Chilled water pump	Off	On	Off
Condensing water pump	Off	On	On
Cooling tower fan	On	On	On

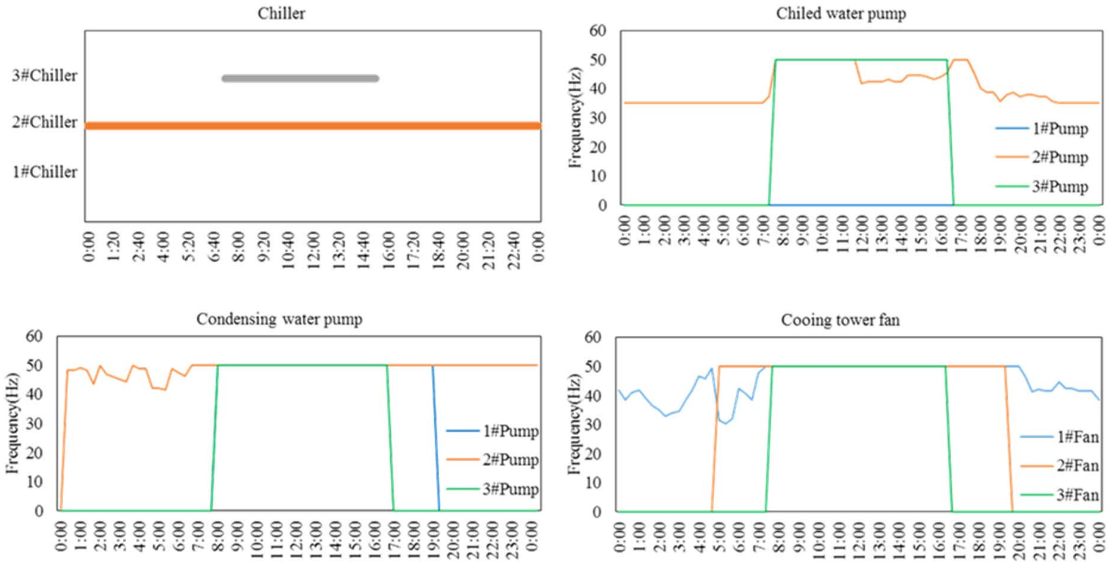

Fig. 3. The operating status of each electric equipment after energy savings retrofit.

Fig. 3 displays the running status of each electric equipment in the chiller plant after the energy savings retrofit. The 2# chiller is still running all day long, however, the 3# chiller is only running on daylight. The chilled water pumps and the condensing water pumps, as well as cooling tower fans, are running with variable frequency. Figure 4 presents the results of the energy savings retrofit, the variable trends of the hourly power before and after the energy savings retrofit.

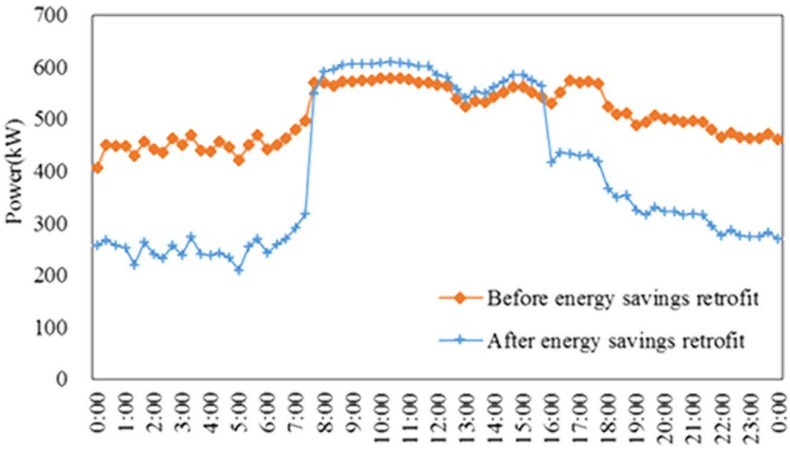

Fig. 4. Variable trends of the hourly power before and after the energy savings retrofit.

After the energy savings retrofit, the hourly power was largely lower than before in the night and slightly higher than before in the daytime. The reason is that the cooling load in daytime is much higher than that in the night. The subjective operation of pumps and fans may have a certain effect on the efficiency of the chillers and that may lead to a little declination of the indoor comfort. So the power in the daytime after the retrofit may be slightly higher than before in order to meet the cooling load. From the point of view of the whole day, the hourly power was much less than before. Figure 5 presents the global energy consumption from each electric equipment. After the energy savings retrofit, the energy consumption of cooling tower fans, the chilled water pumps, the chillers and the condensing water pumps had respectively decreased by 10%, 21%, 25% and 35%. Even the energy consumption of the chiller is much larger than the other three devices, the amount of energy savings of the three devices is not small from the yearly point of view. During the typical days, the energy consumption of the chiller plant decreased by 2416.8 kWh along with the energy savings of 24.6%.

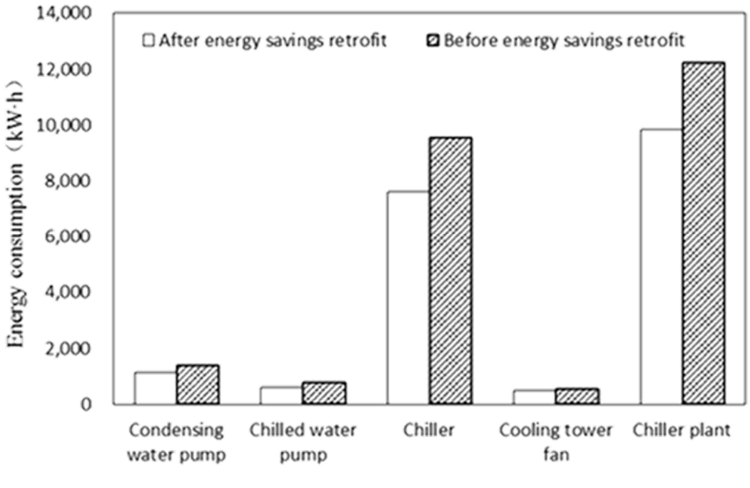

Fig. 5. The global energy consumption before and after the energy savings retrofit.

We consider EER (energy efficiency ratio) as the index to evaluate the energy efficiency. The tendencies of the EER before and after energy savings retrofit varied along with the load indoor for a typical day as shown in Figure 6.

EER has been greatly improved after the energy savings retrofit. The implementation of the web-based online control system makes a higher EER under lower load ratio operating condition. The average EER before the implementation is about 2.04 and the average EER after the implementation is about 3.21, 57.8% which is higher than before.

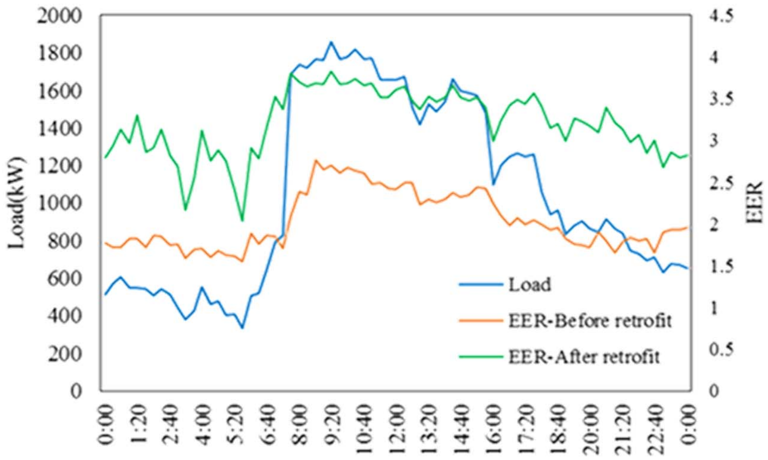

Fig. 6. The global energy consumption before and after the energy savings retrofit.

4. Discussion

The ultimate purpose of the energy savings retrofit is to decrease the energy consumption and improve the energy efficiency of the chiller plant on the premise of sustaining the indoor com-fort by control measures. The present study illustrates that the purposes of the energy savings and the improvement of energy efficiency can be achieved via a web-based control system. Under the limit of the objective condition, the chiller plant always operated under partial load. The online control platform based on Modbus communication is exactly adaptive to solve the problem of high energy consumption under partial load. There are numerous electromechanical equipment's in the chiller plant which should work with high efficiency and low energy consumption. On account of the advantage of distributed control and concentrated management of the control system, it is adaptive for this kind of energy savings retrofit for the chiller plant in a large public building. The current control program is not quite optimal because of the limit of the objective condition. The control algorithm needs further optimization to improve the energy savings ratio.

The global energy consumption during the typical days was decreased by 2416.8 kWh of the chiller plant. That means the energy can be saved for 217512 kWh in the whole air-conditioning time. It can be proved from the above analysis that this kind of chiller plant has a vast of energy savings potential. It can also provide a reference for other similar energy savings retrofits.

4. Conclusions

This study demonstrates an innovative control platform which takes advantage of distributed formation and networked transmission simultaneously which was applied it in a practical chiller plant in a large public building. The result shows that this kind of control platform can be beneficial for the energy savings. The power savings potential was up to 2416.8 kWh during a typical day. Furthermore, the energy consumption was decreased by 24.6%. According to the electric unit price in the locality, the investment pay-back period would be two or three years. By means of the optimal control, the energy consumption can decrease along the in-vestment which can be recovered in a short time.

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